USING XR FOR IMPROVING SCIENTIFIC DISCOVERY WITH NUMERICAL WEATHER MODELS

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Earth science (ES) digital twins will help us understand the complex interactions and interrelationships that make up our Earth system and the impacts of earth science phenomena on it. Our work addresses two underdeveloped areas in current ES digital twin work: improving the understanding and interaction with ES model outputs by using Virtual and Mixed Reality (XR) tools and improving the non-intuitive mapping of continuous ES natural phenomena to gridded reference frames in current numerical models.

Traditionally, scientists working on ES view and analyze the results of calculated or measured observables with static 1-dimensional (1D), 2D or 3D plots displayed on flat computer screens or paper. Using such limited mediums, it can be very difficult to identify, track and understand the evolution of key features due to poor viewing angles and the nature of flat computer screens. In addition, numerical models, such as the NASA Goddard Earth Observing System (GEOS) ES model, are almost exclusively formulated, visualized and analyzed in an Eulerian reference frame with fixed grid points in space and time. However, ES phenomena such as convective clouds [1], hurricanes, volcanic activity[2, 3], and wildfire smoke plumes [4, 5, 6] are visualized and analyzed in a Lagrangian reference frame: therefore it is often difficult and unnatural to understand these phenomena in relation to each other, visualized either in an Eulerian or Lagrangian context.

In 3D visualizations, data generally takes one of three forms: gridded (e.g., voxelized) data [7, 8], where space is divided into regions; point clouds [9, 10], where data is represented as a set of points; and meshes, where objects are rendered as surfaces composed of small polygons (usually triangles). A gridded, Eulerian reference frame has been the default representation for the 2D visual analysis of atmospheric data in part because the numerical methods used to generate atmospheric model data in the first place use a gridded approach, with equations defining the relationships between the physical variables in each of a grid's cells across successive timesteps. In our work, we are particularly interested in data from GEOS. Another reason why gridded representations tend to be used for visualizing data from such models is because trajectories [11] are difficult to interpret from representations on 2D surfaces, due to line-of-sight ambiguity. Instead of a fixed grid from GEOS, we embed a trajectory model to simulate particles' movement throughout a GEOS run. We then ingest these particle trajectories as animated point clouds with a NASA open source XR toolkit, the Mixed Reality Exploration Toolkit (MRET), and merge GEOS data with ES phenomena data onto one combined visualization that the user can intuitively interact with.

Efficient rendering of arbitrarily large point clouds is an ongoing challenge being addressed by the computer science community [12, 13, 14, 15, 16], with the GPU-based optimizations and efficient GPU memory utilization a common theme of recent advances, especially for XR, where sustained high frame rate is mandatory to save the user from suffering due to simulation sickness. In this work, we describe and evaluate our progress in choosing and implementing appropriate methods for rendering arbitrarily large point clouds within MRET for XR.

While tracking the XR headset enables the immersion of a user within a 3D scene of a data visualization, tracking of XR handheld controllers or user's hands enables us to implement intuitive user interactions with the visualized datasets. Conventional tools require a user working with an ES visualization to conduct many interactions to commit their intended selections or manipulations with a visualized dataset; for example to specify a set of points in 3D space. Doing so in a 2D flat screen interface has traditionally required specifying a set of points in three distinct 2D coordinate systems (XY, XZ, and YZ), which is cumbersome. In other scientific domains, it has been shown that specifying or selecting a location or volume in XR using handheld controllers or tracked hands allows for greater speed and accuracy. We anticipate the same will hold true for atmospheric data, and we will share initial results of measuring the utility of such an interface. Notably, as the data being visualized is generated by GEOS as a prediction based on initial conditions, an intended application of our tool is to serve as part of an

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iterative feedback loop. Through XR, a scientist will review and manipulate a GEOS model run, modifying the conditions as needed to do subsequent runs of GEOS. Thereby, XR-based improvements to speed and accuracy of 3D tagging of points minimizes the effort required by both the scientist and the computer cluster conducting the necessary calculations.

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